Engineering Note for

E-906 Tube Assembly

Project: E906, P-25 (LANL)

Title: E-906

Author: Matt Fagan, AET-1, Los Alamos National Laboratory

Date: 12/2011

Reviewers: Walt Sondheim, P-25, Los Alamos National Laboratory

John Ramsey, P-25, Los Alamos National Laboratory

Reviewer's comments on February 7, 2012:

(1) The EN is in pretty good shape but it does not at this time demonstrate that all stresses in the assembly are below allowable values. This does not mean the as-built assembly is not acceptable! More detailed calculations or more discussion is probably all that is needed to finish the EN. Specific comments are embedded in the EN.

(2) It is difficult to see details in the images provided. No detailed drawings were provided. I checked the EN based on what I could discern in the images and details given in the text. I'll see more details when I inspect the unit.

(3) Everything looks good until Calculation #4. The result is only valid if the shear is transferred between the upper and lower 1020 members as assumed in the calculation. I see no evidence of this in the images. I doubled checked this comment with our analysis group. Hopefully, the inspection will reveal details that support the assumption, like a glued assembly of tubes and 80/20 structural members. This assumption shows up in other calcs.

(4) There are three cases of laying the assembly on timbers. In these cases, bending stresses are above the allowable value if you don't accept the assumption noted above in (3). I think these cases illustrate how you want to handle the assembly and how you don't want to handle it. (Stresses don't have to be below allowable values for cases you say you won't do.)

(5) The 80/20 connection load limits for pull-out and sliding should be discussed with 80/20 technical staff to see if they can provide data for the multi-fastener connections used in the assembly. If they don't have loads for critical connections then you can test your specific joint.

Andy Stefanik

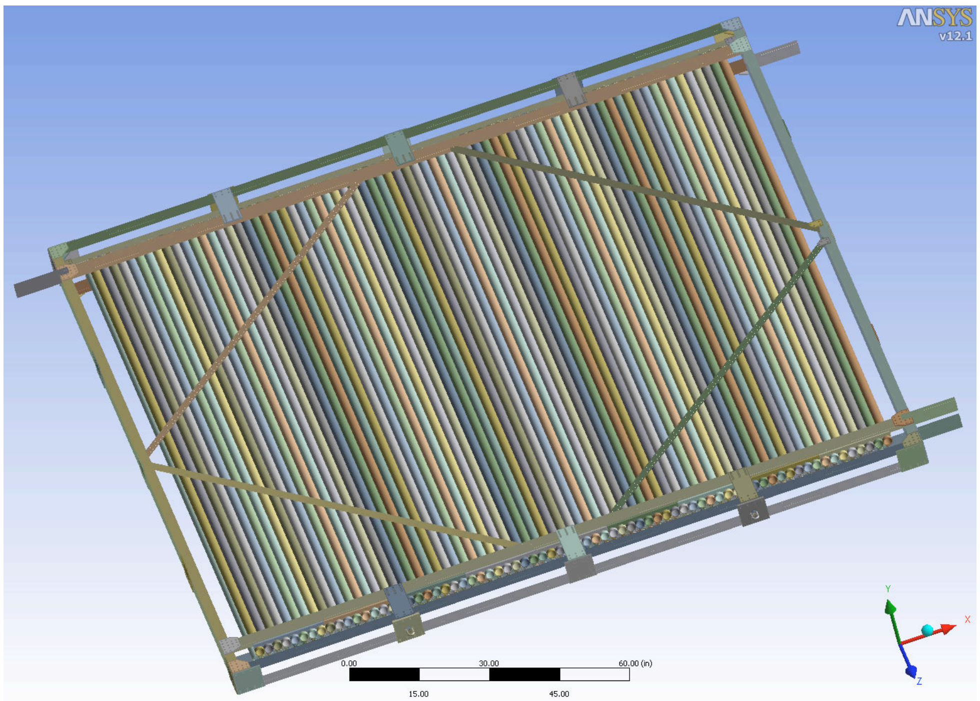
Stefanik@fnal.gov

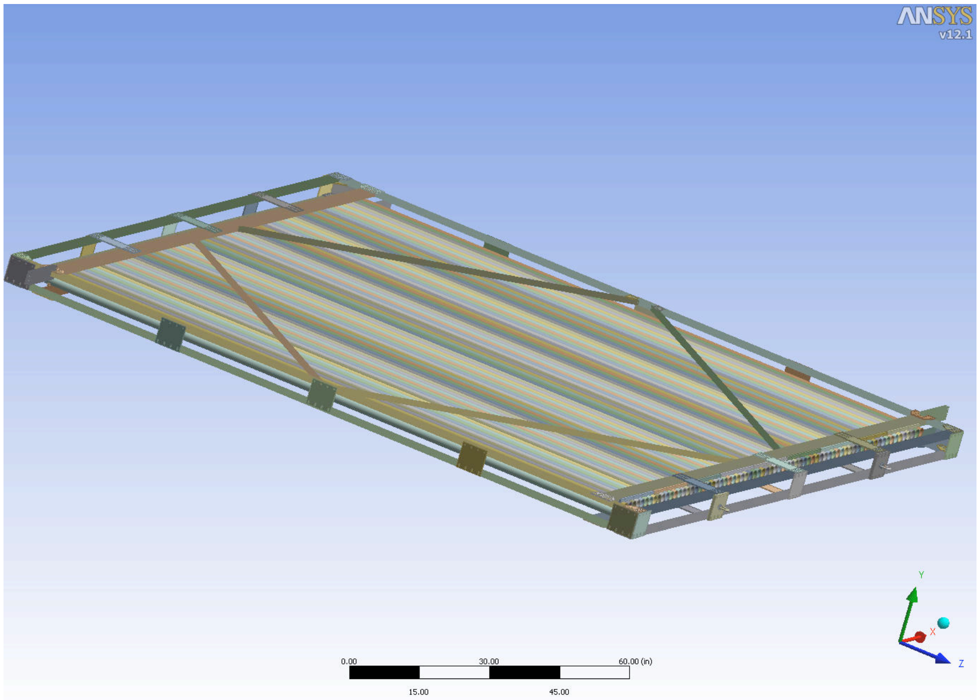
ABSTRACT:

The following calculation note pertains to the E-906 Prop Tube Assembly, as developed by Ming Liu and Walt Sondheim. These calculations describe the ability of the Tube Assembly to handle service and handling loads.

DESIGN:

Two rows of tubes are nested one on top of the other, but staggered. A bead of glue is placed longitudinally at the tube to tube interface. This glue will provide additional structural support, but it will not be taken credit for in the structural analysis for simplicity. Additionally, uncertainties regarding the strength of the glue and its ability to adhere to the aluminum tube make it difficult to include in the analysis.





ANALYSIS:

Refer to the Appendix in "Mechanical Engineering Design", 4th Edition, Shigley and Mitchell, for maximum moment, stress, and deflection formulas. Refer to Appendix C, "Mechanics of Materials", Second Edition, Gere and Timoshenko for formula and explanation of the parallel axis theorem.

The frame is composed primarily of 80/20 Inc. brand extruded aluminum beams. Plates used to join the 80/20 Inc. beams are also produced by 80/20 Inc.

Aluminum allowable stresses are obtained from the Aluminum Design Manual published by the Aluminum Association. (Which Edition? I'm using the 6th, Oct 1994, so my values differ slightly from yours.) Part I-A, Table 3.3-1 lists the 6061-T6 minimum tensile ultimate stress as 38 ksi, and the minimum tensile yield stress as 35 ksi. Part I-A, Section 1.3 describes safety factors to be applied. Building type structure safety factors are used. The allowable tensile stress is the lesser of the minimum yield strength divided by a factor of safety of 1.65, or the minimum ultimate tensile strength divided by

stefanik 2/3/12 2:50 PM
Deleted: Bridge

a factor of safety of 1.95. Thus, an allowable tensile stress of 19,487 ksi shall be used herein. The allowable shear stress is calculated using the Aluminum Design Manual Part 1-A, Section 3.4.20, where $F_s=(F_{ty}/1.732)/n_y$. The value for n_y is obtained from Table 3.4-1 and is 1.65. The allowable shear stress is then 12,247 psi. Use 12,000 psi. (Note: Minimum Fsy is given as 20 ksi; there is no need to estimate it using 0,577Fty.

Part I-A Table 3.3-1 lists the minimum compressive yield as 35 ksi.

stefanik 2/3/12 3:02 PM
Deleted: 24

1010, 1020, and 1030 members are made from 6105-T5. The Aluminum Design Manual Part 1-A, Table 3.3-1 lists the 6105-T5 minimum tensile ultimate stress as 38 ksi, and the minimum tensile yield stress as 35 ksi. Part I-A, Section 1.3 describes safety factors to be applied. Building type structure safety factors are used. The allowable tensile stress is the lesser of the minimum yield strength divided by a factor of safety of 1.65, or the minimum ultimate tensile strength divided by a factor of safety of 1.95. Thus, an allowable tensile stress of 19,487 ksi shall be used herein.

stefanik 2/3/12 3:47 PM
Deleted: Bridge

The 80/20 Inc. joining plates are also made from 6105-T5 material. Accordingly, the allowable tensile stress for these parts is also 19,487 psi. The allowable shear stress is calculated using the Aluminum Design Manual Part 1-A, Section 3.4.20, where $F_s=(F_{ty}/1.732)/n_y$. The value for n_y is obtained from Table 3.4-1 and is 1.65. The allowable shear stress is then 12,247 psi. Use 12,000 psi.

These allowable stresses are good outside the HAZ, heat affected zone of any welds.

It is good to work though deriving the allowable stresses using safety factors for this ASD design. However in general, be sure to check the allowables listed in the Stress Table for your material and type of stress.

The AISC Manual of Steel Construction is used to determine allowable tensile and shear stress for the fasteners. The allowable tensile stress is taken as 1/3 of the minimum ultimate tensile stress. The allowable shear stress is taken as 0.17 times the minimum ultimate tensile strength for bearing connection, when threads are included in the shear plane. The fasteners used for the frame construction are Alloy 4037 quenched and tempered steel according to the manufacturer. The ultimate tensile strength of this material is 101,000 psi. Consequently, the allowable tensile stress is 33,650 psi. The allowable shear stress is 17,170 psi.

Calculation # 9 should be here because it overrides the numbers in the previous paragraph in bolted 80/20 connections.

Calculation # 1

Analyze the one tube alone to determine if it can support its own weight, simply supported at the ends.

Calculate weight of tube,

d_{outer} = 2.00 in.

d_{inner}= 1.93 in.

$t_{tube\ wall}$ = 0.035 in.

$Weight_{single\ tube}$ = (cross sectional area)(length)(density)

$Area_{tube\ cross\ section}$= π [(1.0 in.)^2 – (0.965 in.)^2] = 0.2161 in.^{2}

$Density_{aluminum}$ = 0.1 lb/in.^{3}

Length = 144 in.

$Weight_{single\ tube}$ = 3.11 lb

$Weight_{single\ tube}$/length= 0.0216 lb/in

$I_{single\ tube}$ = π [(d_{outer})^4 – (d_{inner})^4] / 64 = 0.1043 in.^{4}

Maximum moment for a simply supported beam with a distributed load is

M_{max} = (w l^2)/8 = 56 in-lb

w = 3.11 lb/144 in. = 0.0216 lb/in.

l = length = 144 in.

σ_{max} = M c/I = (56 in-lb)(1.00 in.)/0.1043 in.^{4} = 537 psi

c = tube radius = 1.00 in.

δ_{max} = (5wl^4)/(384EI) = 0.12 in.

$E_{aluminum}$ = 10,000,000 psi

Tubes are aluminum 6061-T6. The calculated stress is well below the 19,487 psi allowable tensile stress and is therefore acceptable. Deflection is small. < 0.12" if the glue holds. Stress is also low enough so that local tube wall buckling should not be a concern (This is confirmed by checking the Stress Table. Glued joints not taken credit for, and ends are clamped by the scalloped pieces. Thus, tubes individually are acceptable.

At this point, the tubes are empty.

Calculation # 2

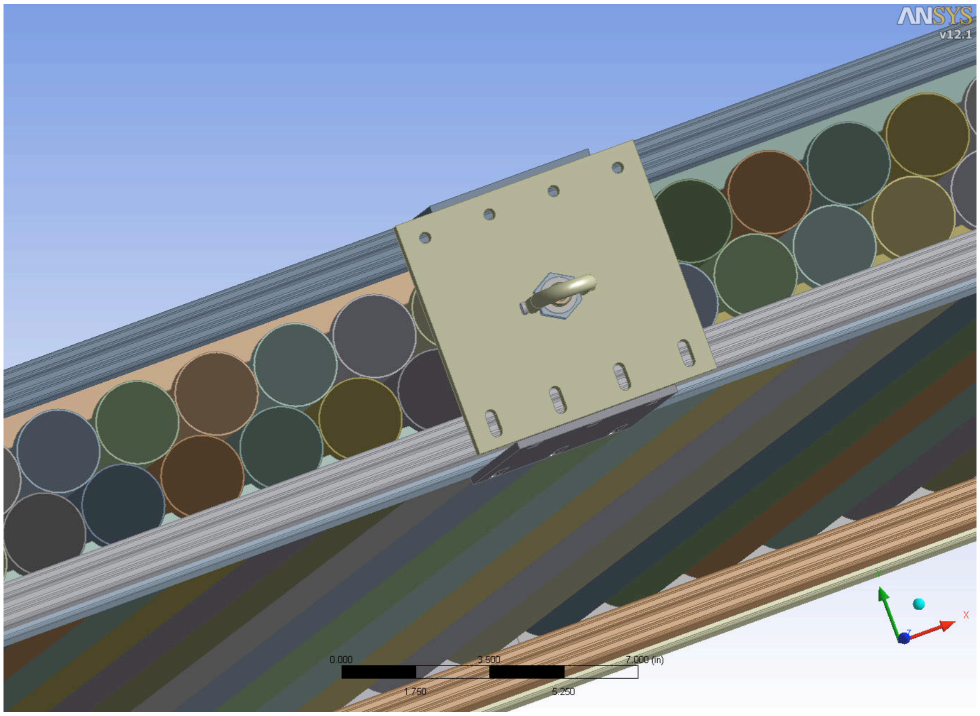
Calculate weight of tube array. Each tube weighs 3.11 lb, and there are 144 tubes. Thus total tube weight is 450 lb. Add 10% for glue. For analysis purposes, use:

$Weight_{tube\ array}$ = (450 lb)1.1 = 495 lb

Weight of the structural members must be considered. Use a total weight (tubes and structural frame) of 700 lb.

Estimate frame weight: Assume > 1030 unit weight to account for all hardware since there is no drawing. Perimeter = 2(12.7'+12.7') = 50.8'. 50.8'(1.5 pounds/ft)(2 layers of 1030) ~= 150 pounds. Total weight ~= 650 pounds; 700 pounds looks ok.

Calculation # 3 – Lifting Features



Frame in vertical position (tube axes perpendicular to floor)

A lifting plate and swivel hoist ring will be used at each corner. In the previous image, the lift point does not appear to be at a corner. So I am going by what you wrote, the lifting rings are at the corners – PLEASE CONFIRM. The plate will be 5/8 inch thick and made from 6061-T6. A Carr-Lane swivel hoist ring (CL-1000-SHR-1) with a 1000 lb capacity will be mounted to the plate. The swivel hoist ring bolt is 0.54 inches long, and the plate is 0.625 inches thick, so sufficient engagement exists. Calculate thread shear stress in the mounting plate (frame in upright position).

$A_{\text{shear, 5/8” threads in the hoist ring mounting plate}} = \pi(5/8 \text{ in.})(0.625 \text{ in.})(1/2) = 0.61 \text{ in.}^2$

$\tau = V/A_{\text{5/8” threads in the hoist ring mounting plate}} = (1000 \text{ lb})/0.61 \text{ in.}^2 = 1{,}640 \text{ psi}$

Bolt diameter is 3/8-16. Internal thread stripping area is (0.828 sq/in of engagement)(0.375 in of engagement) = 0.31 sq in. $\tau_{average}$ = 1000/0.31 = 3,225 psi <12,000 psi. Note: For general structural use with standard thread form, length of engagement is usually limited to one bolt diameter because the thread stress is nonlinear and the load is fairly low below a depth of one bolt diameter. Stress on the first thread will be much higher than the average.

The allowable shear stress of 6061-T6 is 12,247 psi. Shear stress calculated above is acceptable.

Check tensile strength of eight fasteners which secure the plate to the frame. Use actual load of 350 lb (700 lb frame weight divided amongst two hoist rings).

$A_{tensile,\ 1/4''\ screw} = 0.0318\ in.^2$

$\sigma_{0.25''hoist\ ring\ plate\ screws} = F/A = 350\ lb/(8(0.0318\ in.^2)) = 1{,}376\ psi$

The allowable tensile stress for the fasteners is 33,650 psi. Also, refer to Calculation #9 below.

You should compare the load/stress to the connection load limit in calculation #9.

Frame in horizontal position (tube axes parallel to floor)

The plate is secured to the frame with eight 0.25 inch diameter screws. Check shear strength of screws.

$A_{shear,\ 1/4''\ screw} = 0.0269\ in.^2$

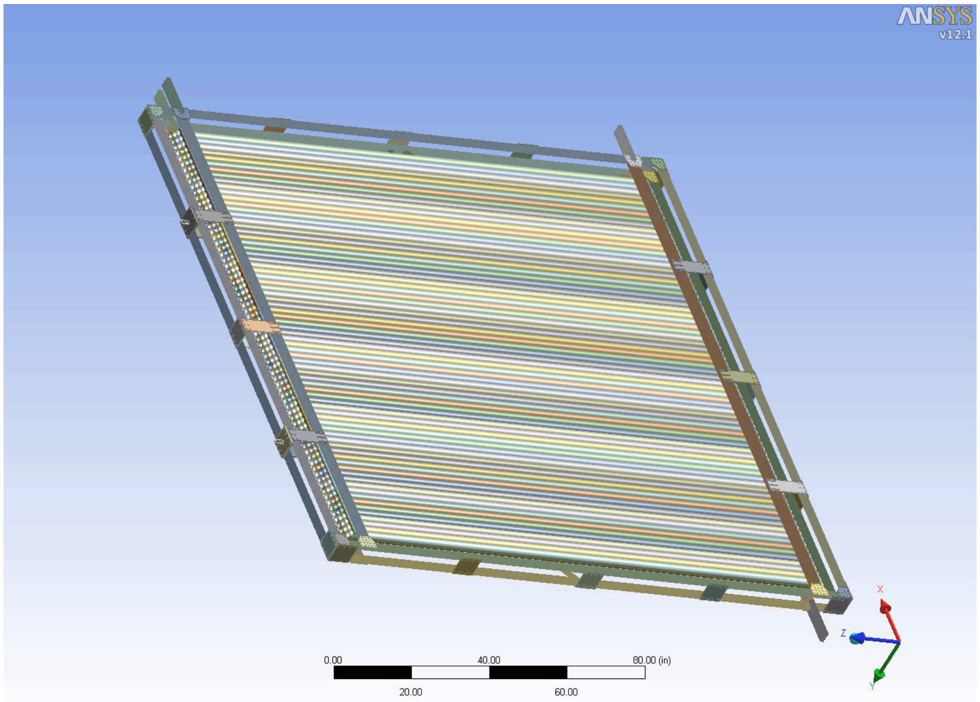
$\tau = V/A_{shear,\ eight\ 1/4''\ screw} = (350\ lb)/(8(0.0269\ in.^2)) = 1{,}626\ psi$

The allowable shear stress is 17,170 psi. Refer also to Calculation #9.

You should compare the load/stress to the connection load limit in calculation #9.

Calculation # 4 – Stresses in Frame Due To Lifting

The frame may be lifted from the horizontal position (frame parallel to floor) into the vertical position.



Frame in horizontal position (tube axes parallel to floor)

The frame would be supported along two opposite edges of the frame. Total frame weight is estimated at 700 lb. This will be a distributed load between the two supported ends. Maximum bending moment will occur between the supported ends.

$M_{midspan} = wL^2/8$ or $FL/8$

Where:

L=length of span

w = distributed load = 700 lb/152 in. = 4.6 lb/in.

F = total load = wL

$M_{midspan}$ = (700 lb)(152 inches)/8 = 13,300 in-lb NOTE: The load on one end of the tube assembly is ½ (700) ~= 350 pounds (slightly less than 350 pounds because the side beams are supported).

Need to take credit for both top and bottom layers of 1020 structural members. This will mean that shear must be transmitted effectively between top and bottom layers. Check bending stress for situation where top and bottom 1020 layers participate. Use parallel axis theorem to calculate net moment of inertia ($I_x = I_{xc} + Ad_1^2$). Refer to included vendor data attached.

$I_{total} = 2(0.0833 \text{ in.}^4) + 2(0.7914 \text{ in.}^2)(2 \text{ in.})^2 = 6.5 \text{ in.}^4$

$\sigma_{max} = M c/I = (13{,}300 \text{ in-lb})(2.5\text{in.})/6.5 \text{ in.}^4 = 5{,}116 \text{ psi}$ NOTE: This result is only valid if as you say above the shear is transferred between the upper and lower 1020 members. I see no evidence of this in the images.

The allowable tensile stress is 19,487 psi for the 6105-T5 1020 members. Consequently, the calculated stress is acceptable. This conclusion is not accepted yet; need shear transfer details. I will continue checking the calcs as if it is correct.

Maximum deflection is calculated as follows.

$Y_{max} = 5wL^4/(384 EI) = 0.5 \text{ in.}$

E = 10,000,000 psi for aluminum

No credit is taken for the tubes. Actual deflection will be less than this.

Maximum shear load occurs at each supported end, and is equal to 700 lb/2. Shear will be carried on either side of the frame, so each side must carry 175 lb. Strap plates are 5.75 in. x 6.00 in. and are 0.188 thick. Shear stress is calculated as follows.

$A_{shear} = 6.00 \text{ in.} \times 0.188 \text{ in.} = 1.13 \text{ in.}^2$ This is difficult to see without a sketch. Why did you use 6”? Centerlines of the 1020 structural members are separated by 4”. Seems like to check transverse shear you would use something like 4”- ¼” = 3.75”.

$\tau = V/A = 175 \text{ lb}/1.13 \text{ in.}^2 = 155 \text{ psi}$

The allowable shear stress in the plates is 12,247 psi.

Calculate stress in the screws which attach the strap plates to the 1020. Four of the five strap plates will be taken credit for. Four 0.25 inch diameter screws in each plate must react both the actual shear force (175 lb/8 screws = 22 lb) as well as the couple developed by 175 lb over a lever arm of 5 inches.

$(175 \text{ lb})(5 \text{ in.}) = 8(2.8 \text{ in.})V_{couple} + 8(2.0 \text{ in.})\, V_{couple}\, (2.0 \text{ in.}/2.8 \text{ in.})$ The strap plate at the end of the beam takes the full 175 pound shear. Shouldn’t the 8’s be 4’s? A sketch will make this calculation clearer. Why is the (2.0 in./2.8 in.) ratio applied?

$V_{couple} = 26 \text{ lb}$

$V_{lateral\ load} = 175 \text{ lb}/8 \text{ screws} = 22 \text{ lb}$ The strap plate at the end of the beam takes the full 175 pound shear. Thus, V lateral load = 44 pounds.

The angle between the vectors of the two shear force components listed above is?

V_{total} = 26 lb + 22 lb = 48 lb

$\tau = V_{total}/A_{0.25\text{ in. diam. screw}}$ = 48 lb/0.0269 in.^{2} = 1,784 psi

The allowable shear stress in the screws is 2,168 psi, per Calculation #9. The directions of the two shear forces are 45 degrees apart, which will lower the stress.

Frame in vertical position (tube axes perpendicular to floor)

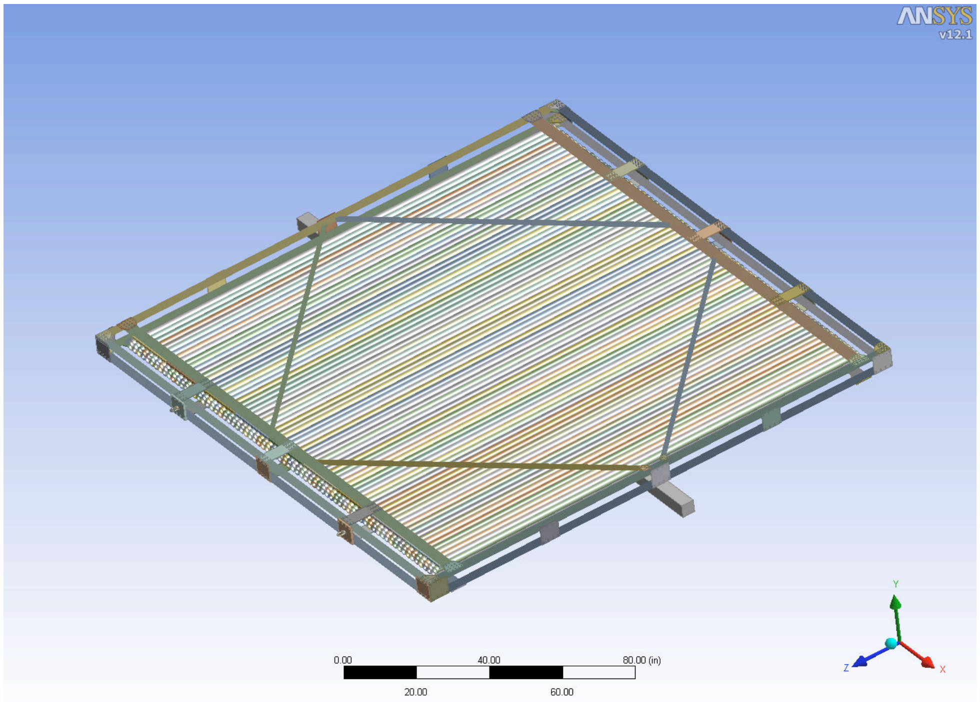
Stresses in the frame are minimal in the vertical position. Loads are well distributed throughout frame, no significant bending moments occur, and stresses are primarily membrane through the frame members. Loads are well distributed from the lifting lug locations.

Shear is transmitted between the lower frame and upper frame via the five plates (10 plates on each side looking at front and back) that are located on each of the four sides, and attached via screws. While the plates are not continuous, they do transmit shear given their aspect ratio. Part of the calculation addresses shear on the screws attaching the plates due a moment created (shearing action tries to rotate plates).

The components that support the tubes at the ends will also assist in carrying shear, but no credit is taken for this (conservative).

Calculation # 5

Calculate bending stress and shear stress for the situation where the frame is supported by a support that runs across the middle of the frame. In other words, frame is set down on a 4” X 4” wood member lying on the floor. The wood member runs across the frame mid-span perpendicular to the tube axis direction.



Attached 1020 information shows the moment of inertia about the weak axis of a 1020 member to be 0.0833 in.^{4} The tubes are supported at the ends via the scalloped brackets. The bottom 1020 pieces (one on each side) will initially be considered to carry the load. Use the case of a cantilevered beam whose length is 76 inches. Point load is 700 lb/4 or 175 lb.

Moment $_{max}$ = (175 lb)(76in) = 13,300 in-lb

σ_{max} = M c/I = (13,300 in-lb)(0.5in.)/0.0833 in.^{4} = 79,832 psi There are two 1220 members on a side, acting separately. Thus, 79,832/2 ~= 40,000 psi.

Stress is too high, as yield stress is 35 ksi for 6105-T5 aluminum.

The rest of the calculation in this section will be exactly like Calculation #4.

Need to take credit for both top and bottom layers. This will mean that shear must be transmitted effectively between top and bottom layers. Check bending stress for situation where top and bottom 1020 layers participate. Use parallel axis theorem to calculate net moment of inertia ($I_x = I_{xc} + Ad_1^2$).

$I_{total} = 2(0.0833 \text{ in.}^4) + 2(0.7914 \text{ in.}^2)(2 \text{ in.})^2 = 6.5 \text{ in.}^4$

$\sigma_{max} = M c/I = (13{,}300 \text{ in-lb})(2.5\text{in.})/6.5 \text{ in.}^4 = 5{,}115$ psi

Bending stress is acceptable since the calculated stress is less than the 19,487 psi allowable tensile stress for the 1020 beams. Reaction load at ends is 175 lb, so shear force of 175 lb must be carried within the frame at the ends. Strap plates are 5.75 in. x 6.00 in. and are 0.188 thick. Shear area is

$A_{shear} = 6.00 \text{ in.} \times 0.188 \text{ in.} = 1.13 \text{ in.}^2$

$\tau = V/A = 175 \text{ lb}/1.13 \text{ in.}^2 = 155$ psi

The allowable shear stress for 6105-T5 is 12,247 psi. Accordingly, this calculated stress is acceptable.

Calculate stress in the screws which attach the strap plate to the 1020. Four of the five strap plates will be taken credit for. Four 0.25 inch diameter screws must react both the actual shear force as well as the couple developed by 175 lb over a lever arm of 5 inches.

$(175\text{lb})(5 \text{ in.}) = 8(2.8 \text{ in.})V_{couple} + 8(2.0 \text{ in.})V_{couple} (2.0 \text{ in.}/2.8 \text{ in.})$

$V_{couple} = 26$ lb

$V_{lateral\ load} = 175 \text{ lb}/8 \text{ screws} = 22$ lb

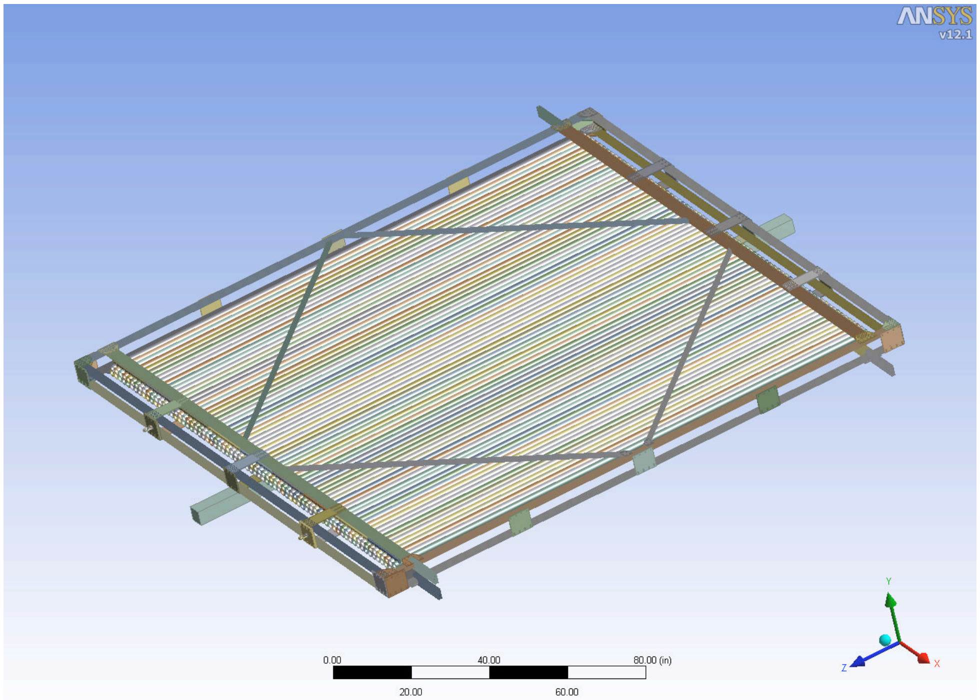
$V_{total} = 26 \text{ lb} + 22 \text{ lb} = 48$ lb

$\tau = V_{total}/A_{0.25 \text{ in. diam. screw}} = 48 \text{ lb}/0.0269 \text{ in.}^2 = 1{,}784$ psi

The fastening hardware is AISI 4037 quenched and tempered steel, according to the 80/20 vendor. The allowable fastener stress is 2,168 psi per Calculation #9. The directions of the two shear forces are 45 degrees apart, which will lower the stress.

Calculation # 6

This calculation is similar to Calculation #5 above, but the wood beam placed on the floor runs coincident with the tubes. It supports the frame in the middle, but 90 degrees to the wood floor support in Calculation #5. The frame is square and there are more support members running across the ends so stresses will be lower.



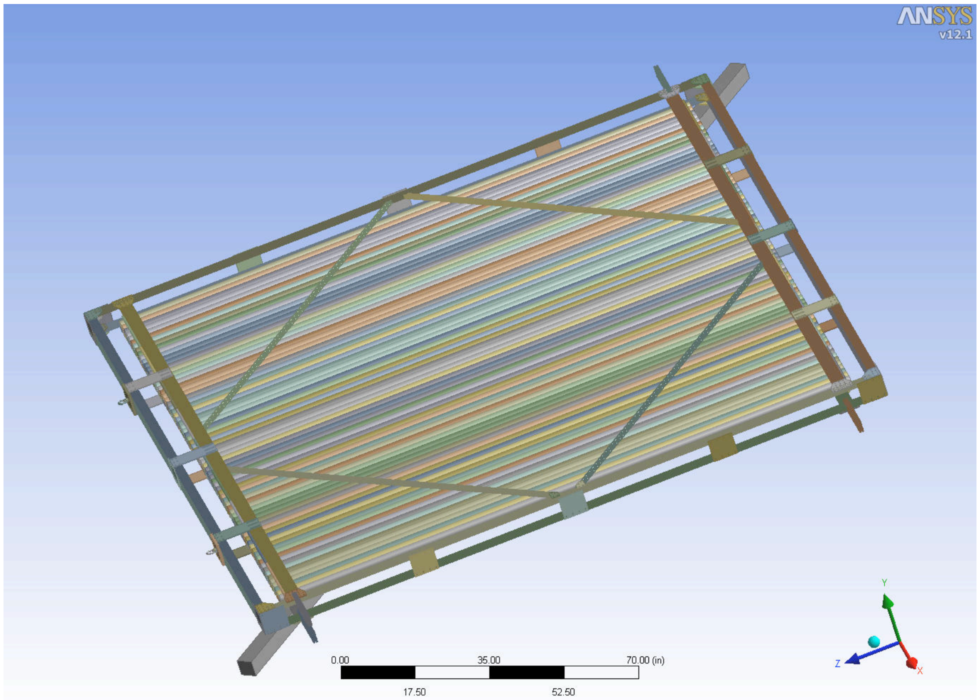
Moment$_{maximum}$ = 13,300 in-lb (from above, as frame is square) This is worse case moment. In calculation #5, you have a cantilevered beam with a point load at the free end of the beam. In Calculation #6, you have a cantilevered beam with uniformly distributed load from the free to the fixed end.

Frame has a lower layer and an upper layer. Strap plates will connect the upper and lower layers, so that the upper and lower layers can be taken credit for in bending, as in Calculation #5. There is a 1020 and 1030 piece on the bottom, and a 1020 and 1030 piece on top. The effective I for these bottom and top layers is more than for Calculation #5. The maximum moment and c are the same. Thus bending stress will be lower. Shear will be transmitted as in Calculation #5, so shear stress is acceptable. Scalloped pieces were not taken credit for. Also this case involves more of a distributed load along beam, versus a point load at the end for Calculation #5.

stefanik 2/7/12 11:48 AM
Deleted:

Calculation # 7

Check bending stress for bending about an axis that runs corner to corner. Frame laid down on floor onto wood beam from Calculation #5 and #6, wherein beam runs from frame corner to frame corner. Use parallel axis theorem again, and use the plate thickness at the corners.



Calculate maximum moment. The area on either side of the wood beam is triangular, with the center of mass 1/3 of the way out from the diagonal bending axis, or 108.2 in./3 or 36 inches.

$\text{Moment}_{maximum}$ = (350 lb)(36 in.) = 12,600 in.-lb

Use parallel axis theorem to calculate net moment of inertia ($I_x = I_{xc} + Ad_1^2$) for the brackets at the frame corners.

$I_{\text{total for brackets at corners}} = \sim 0 \text{ in.}^4 + 8(0.188 \text{ in.})(4.0 \text{ in.})(2.5 \text{ in.})^2 = 37.6 \text{ in.}^4$ This is only true if the ends of the beams are tied solidly together as discussed above.

$\sigma_{max} = M\,c/I = (12{,}600 \text{ in-lb})(2.5\text{in.})/37.6 \text{ in.}^4 = 838 \text{ psi}$ < 19,487 psi for bending.

Need to add shear stress calculation.

Bracket material is 6105-T5 material with an allowable shear stress of 12,247 psi. Calculated stress is acceptable.

Check shear stress in screws that attach the eight plates.

$Moment_{maximum}$ = (5in.)(4 pairs of? plates)F_{plate} (summing moments about lower frame surface at brackets)

F_{plate} =630 lb.

Each plate has at least 12 screws. Each side of the plate has six screws. Force per screw is then 630 lb/6 or 105 lb. Screws are ¼"-20, with a shear area of 0.0269 in.^{2} The shear stress in the screw is calculated as follows.

$\tau = V_{total}/A_{0.25\text{ in. diam. screw}}$ = 105 lb/0.0269 in.^{2} = 3,904 psi < allowable stress of 17,170 psi.

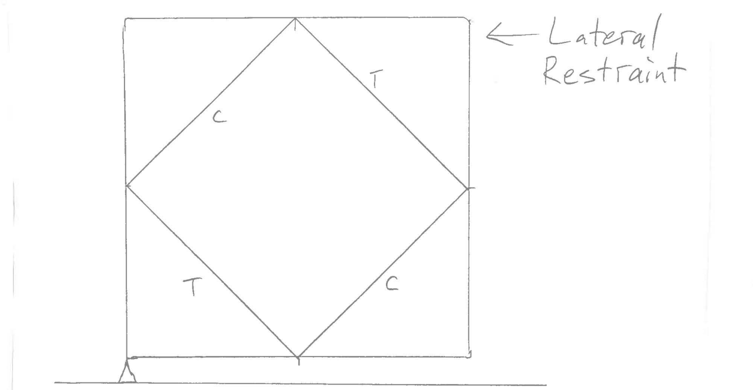
The "connection failure stress" calculated in Calculation #9 is 6,505 psi. The situation described in this calculation is not a standard service condition, but rather an abnormal event. Additionally, no credit was taken for the diagonals participation in reacting the moment, nor for the vertical (web type) strapping plates at the corners, nor the inherent strength of the tube type array within the frame. Taking credit for these effects would reduce stress significantly. Based upon the aforementioned, the situation is judged to be acceptable. The stated connection failure stress in calculation #9 is 2,168 psi < 3,904 psi. It is hard to see the details in the images but why not add another connector plate on the inboard side of each 1020 member to meet the connection allowable stress?

There is too much hand waving to the "acceptable" judgment. I don't see why anyone would support this assembly on the diagonal so just prohibit it and delete this calc. Alternatively, you can add more plates or get a higher connection rating as discussed in calculation #9.

Calculation # 8

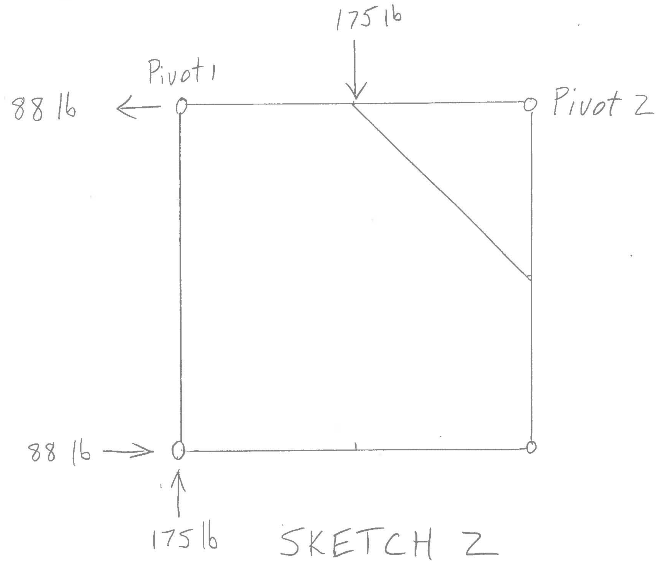
The following calculation will consider frame skewing (i.e. frame tendency to go from a square to a parallelogram shape). This deformation mode is what the four diagonal members are used to prevent. This scenario would cover an event where the frame is lowered onto one corner while providing lateral restraint. The following will calculate the stress in the diagonal, the attachment plate and the screws.

As the frame tries to skew, two of the four top diagonals will be placed in tension, and two in compression. The same holds true for the bottom layer. Only the diagonals placed in tension will be taken credit for since the compressed two could bow. Refer to Sketch 1 below.

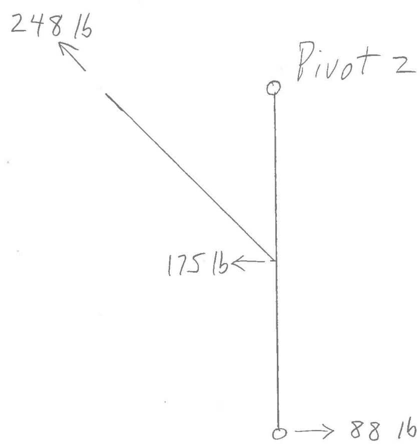


SKETCH 1

The total frame weight is 700 lb. Frame corner connections will be assume to be pinned, with all of the support provided by the diagonals. Half of the load carried by the bottom layer of four diagonals , and half carried by the top layer. Each top layer tensile diagonal then carries 175 lb (700 lb /2 layers is 350 lb per layer, then divided by two for two tensile diagonals is 175 lb per tensile diagonal) . Summing moments about pivot 1 in Sketch 2, $F_{cross\ piece,\ frame}$ is 88 lb. Summing forces about Pivot 2 in Sketch 3, the force in the diagonal is 250 lb. The diagonal is made from 1010 with a cross sectional area of 0.4379 $in.^2$



SKETCH 2



SKETCH 3

σ_{brace} = F/A =250 lb/0.4379 in.^{2} = 571 psi

The bracket attaching the diagonal is 0.188 in. thick with a min. width of 2 in.

$A_{bracket, cross\ section}$ = (0.188 in.)(2 in.) = 0.376 in.^{2}

$\sigma_{bracket}$ = F/A = 250 lb/0.376 in.^{2} = 665 psi

The brace and bracket stresses calculated above are acceptable as they are below the 19,487 psi allowable stress.

Bracket is attached with two screws on either side. Shear stress in screws is calculated as follows.

$A_{shear, 0.25\ in.\ diam.}$= 0.0269 in.^{2}

$\tau = V_{total}/2A_{0.25\ in.\ diam.\ screw}$ = 250 lb/[2(0.0269 in.^{2})] = 4,647 psi

The "failure stress" calculated in Calculation #9 is 6,505 psi. The situation described in this calculation is not a standard service condition, but rather an event which would constitute "rough handling". Additionally, no credit was taken for the strapping plates at the corners, nor the inherent strength of the tube type array within the frame. Taking credit for these effects would reduce stress significantly. Based upon the aforementioned, the situation is judged to be acceptable. Ok.

The same results hold for the other top layer diagonal, as each is assumed to carry 175 lb.

Calculation # 9

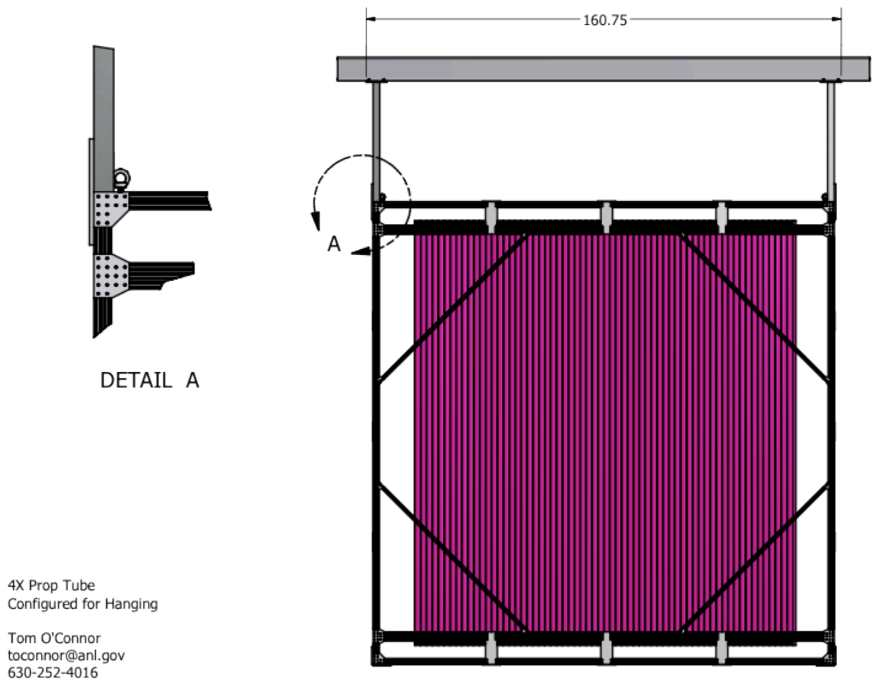
The strength of the fastened connection between joining plates and the 1020 or 1030 members will be evaluated herein. The fasteners which attach the joining plates to the 1020 or 1030 members are ¼"-20 screws. According to the manufacturer, these screws are made from AISI 4037 quenched and tempered steel. These screws go through the joining plates and are threaded into an "economy nut" within the 1020 or 1030 channel. It is difficult to analyze the shear strength (load across fastener) or tensile strength (load along fastener axis) of this connection with respect to the nut pulling out of the extruded part, or sliding along the extruded part. Optimistically one would consider the shear strength or tensile strength of the screw and use a large allowable shear force or tensile force. The 80/20 manufacturer recommends an allowable shear load of 175 lb per the attached page 155 of their catalog. The shear area of a ¼"-20 screw is 0.0269 in.^{2}. The allowable shear stress could be calculated using the vendor load as,

$\tau_{allowable} = V_{vendor\ allowable} / A_{shear}$ = 175 lb/0.0269 in.^{2} = 6,505 psi This is for sliding. Do you have a number for pull-out?

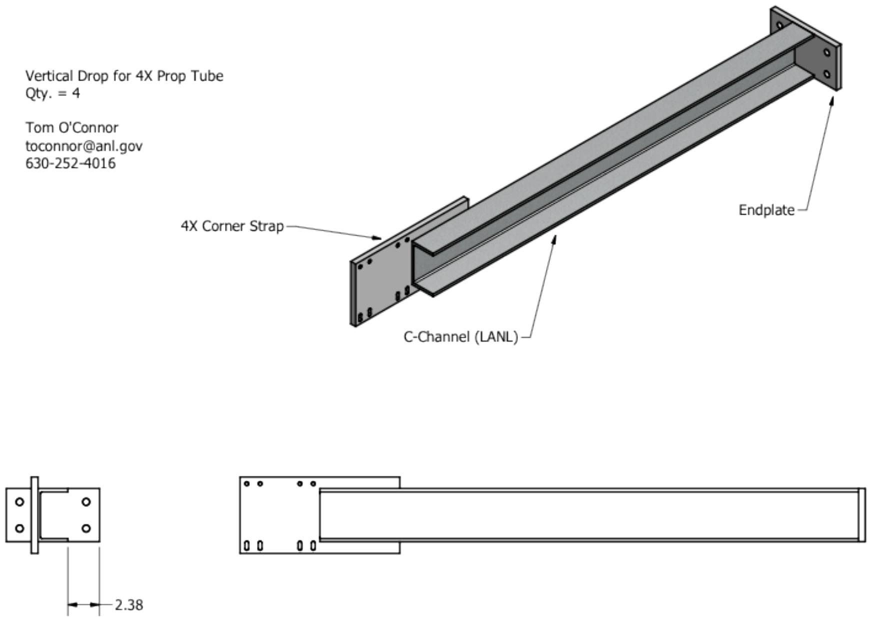
This result is for a 1 or 2-hole per member connector plate. It looks like you have at least 6 holes to bolt the connector plate to the 1020 member, and many more holes for the other member. This connection has to be sturdier than the 1 or 2-hole per member connector plate. You should ask 80/20 about this or do your own test.

This pertains to shear loading of the screw. A factor of safety of three will be utilized, so that the maximum allowable shear stress is 6,505 psi/3 or 2,168 psi. This stress will be treated as the maximum allowable shear stress in the ¼”-20 screws for the frame analysis. This stress will also be treated as the maximum allowable tensile stress for the screws for the frame analysis.

Description of pro-tube assembly hanger:

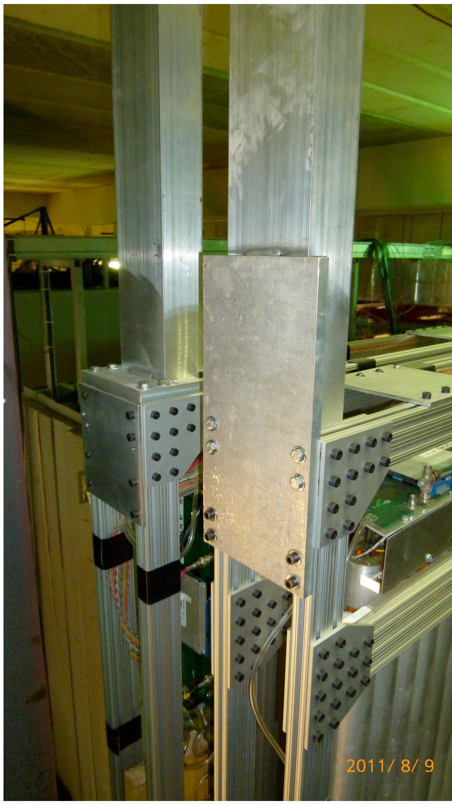


The above figure shows the prop-tube assembly interfaced to an I-beam via two vertical straps, these are bolted to both the pro-tube assembly frame as well as the I-beam. The following picture shows the hanging strap in more detail:



The hanger is made using 6.0 inch Aluminum C-channel with end plates welded at either end. The following is a photograph of this vertical strap attached to a prop-tube assembly:

Here is another detail of the vertical strap:



Details on the C-channel hardware:

- inch bolts ¼” thick C-channel
  - 4” (W) x 2 ½” (H) x 40 ½”(L) for 4X
  - 4” (W) x 2 ½” (H) x 40.375”(L) for 4Y
- AL materials: 6061 alloy
- Attached to cross I-beam with
  - Grade 5 fasteners, followings are from Tom’s email (1/13/2011)
  - Beveled Washers for 1/2" bolt, McMaster Carr Part # 91152A033 (box of ten)
  - Hex Head Screws 1/2"-13x2" long, McMaster Carr Part # 91247A722 (box of ten)
  - Hex Nuts 1/2"-13, McMaster Carr Part # 95045A033 (box of 25) Washers for 1/2

The Aluminum cross I-beams that the vertical strap attach to are 8.0”(H) x 4.0”(W) with a ½” web.

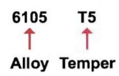
Fractional

Why Do We Use 6105-T5 Aluminum Alloy?

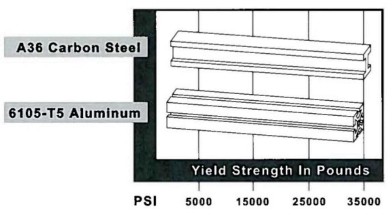
Aluminum Profile Alloys: Number and Characteristics	Tensile Strength - ksi* Ultimate minimum	Ultimate maximum	Yield minimum	Yield maximum
6105-T5 (80/20's Alloy)	38.00	••	35.00	••
6063-T6	30.00	••	25.00	••

*Figures based on material thickness of 0.125 to 1.00"
From The Aluminum Extrusion Manual, published by The Aluminum Association and the Aluminum Extruders Council.

All of 80/20's T-slotted profiles feature the 6105-T5 alloy. An aluminum extrusion alloy is a mixed metal that includes other elements such as copper, magnesium, iron, silicon or zinc. Certain properties such as strength, machinability and corrosion resistance are influenced by the choice of alloy and temper. **Alloy 6105 with a T5 temper, chosen by 80/20, has better machinability and strength than 6063-T6.**

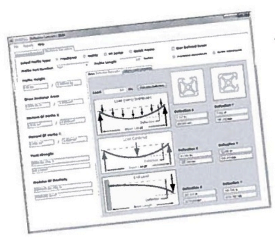


Material Strength Specifications



Minimum Yield Strength In Pounds

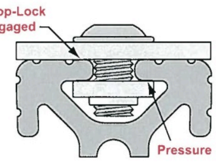
- 80/20®'s 6105-T5 alloy yield strength of 35,000 psi compares to A36 carbon steel's yield strength of 36,000 psi.
- Volume for volume, aluminum weighs about 1/3 as much as iron, steel, copper, or brass.



Fractional

Torque Specifications

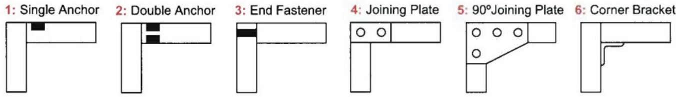
- See table below for the amount of torque in foot-lbs. required to activate the 2° drop-lock feature for T-slotted profiles
- Nut and bolt combination is pre-loaded when tightened to the minimum torque rating
- When properly tightened, fasteners will not loosen even under heavy vibration



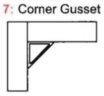
Part Number	Fastener Description	Tested Profile	Minimum Ft-lbs. Torque	Maximum Ft-lbs. Torque
3320	5/16-18 x 11/16 Flanged BHSCS & Economy T-Nut	1515	10.00	15.00
3325	5/16-18 x 3/4 Economy T-Slot Stud, Washer & Hex Nut	1515	30.00	40.00
3360	15 Series Anchor Fastener Assembly	1515-Lite	10.00	28.00
3380	15 Series End Fastener Assembly	1515-Lite	10.00	22.00
3321	1/4-20 x 1/2 Flanged BHSCS & Economy T-Nut	1010	4.00	6.00
3395	10 Series Anchor Fastener Assembly	1010	3.00	17.00
3381	10 Series End Fastener Assembly	1010	4.00	17.00

Fastener Application Tests

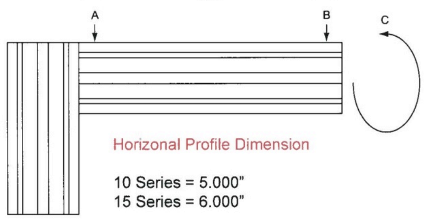
1: Single Anchor 2: Double Anchor 3: End Fastener 4: Joining Plate 5: 90°Joining Plate 6: Corner Bracket



7: Corner Gusset



A: Direct Force
B: Cantilevered Force
C: Tortional Force



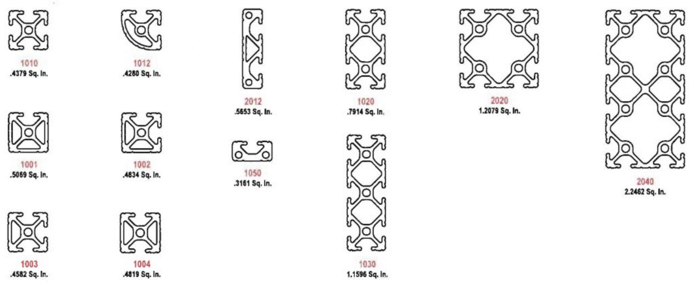
Fastener	1010 Profile			1515-Lite Profile			1515 Profile		
	A (lbs.)	B (lbs.)	C (Inch-lbs.)	A (lbs.)	B (lbs.)	C (Inch-lbs.)	A (lbs.)	B (lbs.)	C (Inch-lbs.)
1	500	250	180	950	625	540	950	1,000	700
2	900	250	260	1,200	700	1,150	1,200	1,200	2,000
3	450	200	325	1,000	500	680	1,000	820	1,150
4	175	50	400	225	200	1,000	225	200	1,100
5	175	50	500	250	200	1,120	250	200	1,260
6	325	75	180	375	225	500	575	225	500
7	325	220	260	375	750	500	575	750	500

Note: Plates, brackets and gussets were attached with 80/20® recommended bolt kits. Fasteners were tightened according to 80/20® torque specifications found at the top of the page.

Test results reflect the connection failure point. Loads at or above these points are not recommended.

80/20® Inc.
The Industrial Erector Set®
THE STANDARD

10 Series Profile Material Specifications



Compatibility Code*: 6-10

Part No.	1010	1001	1002	1003	1004	1012
Material	6105-T5 Aluminum					
Finish	Clear Anodize #204-R1					
Weight Per Foot	.5097 Lbs.	.5900 Lbs.	.5627 Lbs.	.5333 Lbs.	.5609 Lbs.	.4982 Lbs.
Stock Length **	97", 145", 242"	145" or 242"	145" or 242"	145" or 242"	145" or 242"	145" or 242"
Moment of Inertia	IX=.0442"^{4} IY=.0442"^{4}	IX=.0542"^{4} IY=.0493"^{4}	IX=.0492"^{4} IY=.0492"^{4}	IX=.0491"^{4} IY=.0441"^{4}	IX=.0541"^{4} IY=.0443"^{4}	IX=.0400"^{4} IY=.0400"^{4}
Estimated Area	.4379 Sq. In.	.5069 Sq. In.	.4834 Sq. In.	.4582 Sq. In.	.4819 Sq. In.	.4280 Sq. In.
Modulus of Elasticity	10,200,000 Lbs./Sq. In.					

Part No.	1050	2012	1020	1030	2020	2040
Material	6105-T5 Aluminum					
Finish	Clear Anodize #204-R1					
Weight Per Foot	.3679 Lbs.	.6580 Lbs.	.9212 Lbs.	1.3498 Lbs.	1.4060 Lbs.	2.6146 Lbs.
Stock Length **	145"	145"	97", 145", 242"	145" or 242"	145" or 242"	145" or 242"
Moment of Inertia	IX=.0074"^{4} IY=.0323"^{4}	IX=.2253"^{4} IY=.0146"^{4}	IX=.3078"^{4} IY=.0833"^{4}	IX=.9711"^{4} IY=.1238"^{4}	IX=.5509"^{4} IY=.5509"^{4}	IX=3.5168"^{4} IY=1.0513"^{4}
Estimated Area	.3161 Sq. In.	.5653 Sq. In.	.7914 Sq. In.	1.1596 Sq. In.	1.2079 Sq. In.	2.2462 Sq. In.
Modulus of Elasticity	10,200,000 Lbs./Sq. In.					

* See Compatibility Code information on page 152.
** For profile lengths other than stock length refer to page 563 for profile cut to length services.